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Demonstration and Results of Grid Integrated Technologies at the Demand to Grid Laboratory (D2G Lab): Phase I Operations Report

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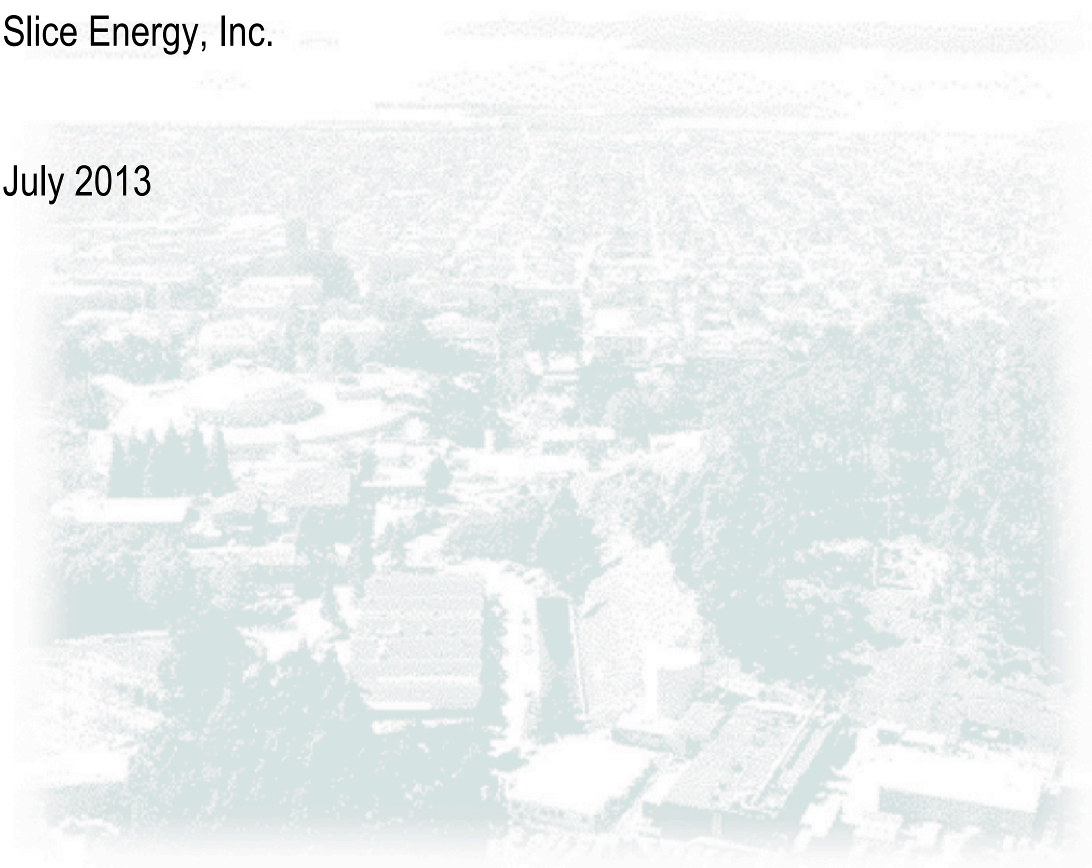

Disclaimer

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The D2G Lab includes equipment and software under long-term loan and/or donation by vendors. This equipment and software is geared toward meeting the demonstration and evaluation goals and objectives. By including these products and mentioning them in this report, Lawrence Berkeley National Laboratory does not intend to endorse either the product or the vendor.

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EXECUTIVE SUMMARY

This report details the operations of the Demand to Grid Laboratory (D2G Lab) demonstrations at Lawrence Berkeley National Laboratory (LBNL) since 2011, or Phase 1. Its purpose is to list the D2G Lab demonstration activities and results, and identify next steps to advance grid-integrated technologies and demand response research.

The D2G Lab was set up at LBNL's Demand Response Research Center in 2011 to support research in the areas of open and related automated DR technologies, end-use devices, and their integration with the electric grid. The D2G Lab advances Smart Grid deployment for commercial, industrial, and residential end-uses, including measurement, communications, and control networks. The D2G lab was created to evaluate the methods to configure low-cost and easy-to-implement demand response communication and control technologies. To meet these goals and functions, the D2G Lab was set up with careful thought toward supporting the DR and grid-integration goals of California.

The D2G Lab provided an R&D test bed such as proof-of-concept studies and demonstrations of pre-commercial technologies, and evaluation of techniques to link demand-side loads with advanced DR capabilities. The monitoring systems, integrated database, and modular setup allowed inclusion of new technologies for commercial adoption. The D2G Lab also provided R&D tools for building systems to support broader U.S. grid integration initiatives. Identifying and improving the flexibility of electric loads will allow the electric grid to be more cost effective and resilient as more intermittent renewables are integrated. The D2G lab also provided a test bed for advanced control systems and related grid-integrated technologies that support the U.S. Department of Energy's (DOE's) evaluation of responsive loads to and from grid transactions.

Demonstrations at the D2G Lab are taking place in two phases. Phase 1 operation started in 2011, and Phase 2 is under way and shall be completed by the end of December 2013. The demonstrations considered technology and integration for different end-users (commercial, industrial, residential, and electric vehicles), equipment, and markets and programs. A technical advisory group was recruited to provide guidance, improve communications, and technology transfer. Table A describes the five demonstration areas that were part of the D2G Lab's Phase 1 activities. The areas also list the initial list of solution providers or vendors that participated in these activities. These demonstration areas are described in subsequent sections.

Table A: Demonstration Areas and Partners

Demonstration Area	Partners
1. Residential Appliances, Thermostats, Plug-load Meters, and HAN.	GE, Cloudbeam, Radio Thermostat, NEST, Itron, SilverSpring Networks
2. OpenADR Technologies and Auto-DR Systems for End Uses and Strategies.	Akuacom, AutoGrid
3. Lighting Controls, Communication, and Technologies	Lunera and NEXT Lighting, Cloudbeam
4. Vehicle to Grid (V2G) and Electric Vehicle Chargers	Coulomb Technologies, AutoGrid
5. Analytics and Visualization	GE, Cloudbeam, Akuacom, AutoGrid

The findings from the D2G Lab Phase 1 operations provided technology transfer and insights to stakeholders that demonstrations are effective means to show R&D concepts and to identify new R&D and deployment areas. The demonstration test bed is also useful for conducting research, identifying empirical evidence, and validating the findings and conclusions that benefit the wider grid integration community. The key findings from the demonstrations described were:

- Research and evaluation of standards-based communication with residential appliances, and demonstrate the pros and cons of different demand response automation architectures that included integration with an Advanced Meter Infrastructure, Open Automated Demand Response and the Smart Energy Profile (version 1.x).
- Open standards that have a compliance and certification framework play a role in information interoperability. Also, an appropriate architecture provides customer benefits in low-cost automation infrastructure and eases DR program participation.
- Data storage, trending, and visualization are required to validate DR and technology performance. The visualization and analytics can assist in measurement and verification for DR and to understand the effectiveness of equipment/device response strategies.
- Our experience in setting up the communications between several devices demonstrated that the design "maturity" in these devices has been problematic. Issues we experienced included incomplete documentation on how to configure the devices, incorrect network install codes and devices configured with incompatible versions of firmware.

These end-use demonstrations show innovative use of OpenADR to achieve interoperability and use of an OpenADR 1.0 client at the device level and allowing customers the choice to easily program their response strategies for DR.

The next steps for the D2G Lab for the second year of operations (Phase 2) will be to continue the existing demonstrations and conduct new ones, to provide a suitable grid integration research and demonstration framework for the FLEXLAB, and to implement a flexible data storage and mining platform to conduct research.

The future demonstrations for the D2G Lab will include OpenADR 2.0 demonstrations compliance process, interoperability with other end uses, interface with Smart Grid standards and building protocols, simulation and visualization tools, and integrated and interoperable energy management using OpenADR and relevant protocols for transactive controls.

CHAPTER 1: Introduction and Background

This report details the operations of the Demand to Grid Laboratory (D2G Lab) demonstrations at Lawrence Berkeley National Laboratory (LBNL) since 2011, or Phase 1. Its purpose is to list the D2G Lab demonstration activities and results, and identify next steps to advance grid-integrated technologies and demand response (DR) research.

The D2G Lab was set up at LBNL's Demand Response Research Center in 2011 to support research in the areas of open and related automated DR technologies, end-use devices, and their integration with the electric grid. These demonstrations continue the DR research and deployment activities since 2002 (Piette et al. 2009). The D2G Lab advances Smart Grid deployment for commercial, industrial, and residential end-uses, including measurement, communications, and control networks.

The D2G lab focuses on the grid integration-related issues such as demand response, microgrids, and electricity reliability. Table 1 provides a broader set of research requirements under each focus area. The D2G Lab was established to test integration of building to grid technologies, distributed energy resources and storage, automated demand response (Auto-DR) technologies, standards, and interoperability. The D2G lab aims to innovate low-cost and easy-to-implement solutions and technologies.

Table 1: Grid Integration Requirements Addressed by the D2G Lab

Demand Response (DR)	Microgrids	Electricity Reliability
• Tariffs and rate design integration in end uses • Communications and telemetry • Commercial, industrial, and residential end uses, automation, and controls • Open Automated DR	• Optimization of distributed energy resources • Distributed energy resources and technologies integration • Vehicle to Grid integration	• Real-time grid reliability management • Customers & markets and market requirements • Load as a resource • Reliability technology issues

Goal and Objectives

The goal of the D2G Lab is to provide a demonstration and test bed for Open Automated Demand Response (OpenADR) standards, Auto-DR technologies, and related Smart Grid activities at LBNL, as well as to provide the outcomes to applications of grid-integrated and DR technologies. These outcomes can be used to identify next stages of research and deployment plans for market design of DR programs and policy decisions.

The objectives of the D2G Lab are to **build and operate** a test bed to facilitate research within LBNL and to demonstrate innovative technologies and approaches to stakeholders. The D2G Lab emphasizes five key concepts:

1. **Open Standards:** What key open standards are available and useful in demonstrating DR capabilities and why is it an important topic?
2. **Interoperability:** Can devices from multiple vendors communicate to send and receive DR signals and other information? What steps and tools are required to achieve interoperability?[1]
3. **Instructive and Illustrative:** How can new technology be configured to instruct and showcase DR systems for researchers, electricity service providers, and policymakers? What potential architecture concepts can be used to connect DR systems?
4. **Inclusion:** How can a new technology be used for both large and small vendors, as well as consumers?
5. **Measurement Based:** What measurement technology and approaches are needed to characterize end-use electric loads?

Functions of the D2G Lab

The overall functions of the D2G lab are to aid demonstrations and support ongoing and near-term research activities that can be implemented into operation incrementally over an initial two-year period of operations through funding from the California Energy Commission's (Energy Commission's) Public Interest Energy Research (PIER) Program. The D2G Lab will identify:

- The test environment for OpenADR open source toolkit, commercial clients, and gateways.
- Types of end-use electric measurement techniques, control systems, and infrastructure to be evaluated and examined for all sectors. This includes, but is not limited to, space requirements, stakeholders, and potential sources of cost share for materials, equipment, and in-kind participation from industry and research partners.
- Equipment, systems, and devices for OpenADR demonstration and testing.

The activities of the D2G Lab, which are primarily focused on demonstration of demand-side integration with the electric grid, includes, but is not limited to:

- Data communications and interoperability issues with buildings (e.g., residential, electric vehicles) DR and energy management systems (Ghatikar et al. 2011, 2012)

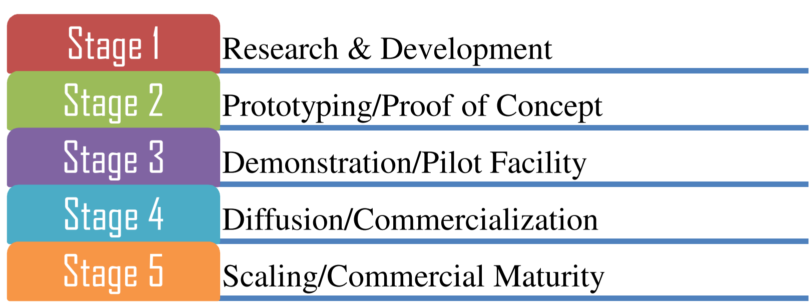
[1] **Note:** The D2G lab does not plan to provide compliance or conformance testing, which will be available in the private sector.

- Wired and wireless communications and monitoring technologies and their interoperability with OpenADR (Piette et al. 2009; OpenADR Alliance 2013).
- Feasibility and cost analysis for use of a DR client within control systems and their scalability and economic feasibility.
- Evaluating performance of end-use device electric load characteristics and load control strategies that integrate energy efficiency and DR control concepts (Motegi et al. 2006).
- Collaborate with manufacturers to specify, evaluate, and demonstrate OpenADR and appliance data exchange requirements and communications technologies for integrated operations within the home area network (OpenSEG 2012).
- Integrated building control systems and components with energy simulation tools to better predict the behavior of building systems and estimate demand savings potentials.
- Cyber-security issues, if/as they arise in different DR-related network architectures (McParland 2009).

Background

To meet these goals and functions, the D2G Lab was set up with careful thought toward supporting the DR and grid-integration goals of California. However, these results are applicable and are relevant to other U.S. states and international activities. The stages shown in Figure 1, for example, support California's vision to commercialize and facilitate the adoption of grid-integrated technologies developed through research and development (R&D) (CEC EPIC 2012).

Figure 1: The Five Stages for Commercial Adoption of DR Technologies



The goals and objectives of the D2G Lab align with the tasks defined in the first three stages and provide the deployment pathways for the following stages. The D2G Lab provides a test bed to conduct R&D such as proof-of-concept studies and demonstrations of pre-commercial technologies, and evaluation of techniques to link demand-side loads with advanced DR capabilities. The monitoring systems, integrated database, and modular setup of the D2G lab allow inclusion of new technologies for commercial adoption. The D2G Lab provides tools to allow R&D of building components and systems that can be designed and controlled to support broader U.S. grid integration initiatives. Identifying and improving the flexibility of electric loads will allow the electric grid to be more cost effective and resilient as more intermittent renewables are integrated. The D2G lab can provide a testing and demonstration test bed for advanced control systems and related grid-integrated technologies that support the U.S. Department of Energy's (DOE's) evaluation of responsive loads to and from grid transactions (U.S. DOE 2012).

Related Activities

Considering that Smart Grid has multiple domains, several U.S. labs, under management of other national laboratories, universities, and private companies, are geared to address specific challenges within the Smart Grid. It is important to recognize the functions and activities of such labs to identify synergies and make valuable contributions to society and industry. This information will allow the D2G lab to collaborate on common areas of interest in the future. Such labs are key in disseminating information through demonstrations of emerging technologies, communication standards, and interoperability. The D2G lab emphasizes demand-side integration into the smart grid. Appendix A contains a list of known U.S. Smart Grid labs, along with their related areas of research, demonstrations, and testing.

Report Organization

The following chapters detail the D2G lab demonstration activities (which were planned for the two years from the Energy Commission's funding), equipment, testing activities conducted during Phase 1, key outcomes, and next steps. This report is organized as follows:

- Chapter 2 describes the demonstration framework and information about the Technical Advisory Group (TAG).
- Chapter 3 details the first year plans, along with test environments, equipment/device, and architecture of the D2G lab.
- Chapter 4 summarizes the demonstration activities at the D2G Lab.
- Chapter 5 presents Phase 1 outcomes, conclusions, and next steps through the Phase 1 operations of the D2G Lab.

A glossary of key terms used in this report and references follow Chapter 5. Appendices contain further details.

This report aims to provide the operational and technical information to a targeted audience, which includes the researchers, utilities, DR Service providers, technology vendors, and regulators such as the California Public Utilities Commission (CPUC) or DOE, which will shape the technology requirements of the DR markets.

CHAPTER 2: Demonstration Framework

Demonstrations at the D2G Lab are taking place in two phases. Phase 1 operation started in 2011, and Phase 2 for future consideration.

- **Building Sector:** Considering that DR applies to many end uses and sectors, we are interested in all end-uses and sectors – residential, commercial, industrial, and vehicles.
- **End-Uses**: The end-uses and their respective DR strategy depend on the type of sector in which OpenADR is being used. Some end-uses are viable, commercially proven options for use in DR events (e.g., lighting and HVAC); others are under demonstration (e.g., appliances, data centers). Demonstrations at the D2G Lab are designed to demonstrate end-uses and their strategies that a building owner may implement in response to a DR event. They will also demonstrate new end uses (e.g., appliances) and different technologies for OpenADR.
- **Equipment/Devices**: Vendors will donate most of the equipment/devices for the D2G Lab. This will help keep the D2G Lab's capital expenditures low and also allow us to directly interact with the industry to bring OpenADR to the marketplace. Because equipment/device purchases are minimal, funds are mostly used to conduct research.
- **DR Markets/Programs**: The use of a particular end-use, equipment/device, and DR strategy will depend upon the type of DR program (utility or independent system operator [ISO]) and response strategy (e.g., ability to respond with day-ahead or day-of DR events). The demonstrations are designed to facilitate end-to-end integration with ongoing utility/ISO programs.

Based on the above framework, Table 3 and the following chapters describe the original D2G Lab's Phase 1 and Phase 2 demonstration plans for the test bed and equipment. This report focuses on Phase 1 operations and related accomplishments from the original plans. The goal of Phase 2 is to focus on the remaining activities from the original plan.

Table 3: Summary of the Original D2G Lab Plans: Phase 1 and Phase 2

	Phase 1	Phase 2
Demonstration Plans	• Install/operate OpenADR toolkit. • Web-based interfaces to vendor's OpenADR 1.0/2.0 servers and toolkit. • Install and operate residential appliances, set-up interfaces to gateway/Demand Response Automation Server (DRAS) (1.0 and 2.0 prototype). • OpenADR 2.0 compliance set-up based on the OpenADR Alliance certification and testing program. • OpenADR systems, technologies, and strategies for varied end-uses, thermostats with wired/wireless communication interfaces. • Install and operate electric vehicle (EV) charger, integration with DRAS. • Visualization of DR simulation (e.g., DR Quick Assessment Tool).	• OpenADR 2.0 server with interfaces to vendor systems. • Interfaces between GE appliances, smart meters, and advanced metering infrastructure (AMI). • OpenADR 2.0 client gateways/devices. • OpenADR 2.0/1.0 interoperability.[2] • LBNL FLEXLAB integration.[3] • OpenADR technologies, strategies for end uses. • Simulation/Modeling prototypes for buildings (e.g., using the Demand Response Quick Assessment Tool, DRQAT). • Irrigation simulation.
Building Sectors	• Commercial, industrial, residential, and EV/plug-in hybrid EV (PHEV).	• Commercial, industrial, residential, and EV/PHEV.
End Uses	• HVAC, lighting, appliances, thermostats, and EV/PHEV, industrial.	• Heating/Cooling technologies, lighting, appliances, EVs.
Equipment/ Software	• OpenADR 1.0 Open Source toolkit, appliances (washer, dryer, refrigerator, and water heater), thermostats, gateway, DRQAT, etc. • OpenADR 2.0 compliant clients, devices/gateways, sub-meters, wired/ wireless systems, EV charger, display/ visualization, etc.	• Smart meters, AMI, OpenADR 2.0 Open Source toolkit, display/visualization devices, building prototypes, etc.
DR Markets/Programs	• Price and reliability, time-of-use rates. • CA utilities' dynamic prices	• Transactive controls, fast responsive loads.

Although the D2G Lab exceeded expectations (e.g., for database integration, communicating thermostat technologies) during Phase 1 of its operations in certain areas, a few demonstrations from the original plans were scheduled for a later time. This was mainly due to logistical

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[2] This activity will result through technical assessment and transition plans for OpenADR 1.0.

[3] The FLEXLAB within LBNL will include a combined controls test-bed for buildings and DR systems, and a visualization/ education space for the purposes of demonstration.

problems such as lack of availability of technologies that met the requirements of the demonstrations and focus on present and future priorities.

The demonstrations that were postponed until Phase 2 were:

- Refrigerated warehouse simulation.
- Systems for DR simulation/modeling (e.g., DR Quick Assessment Tool).
- Comprehensive display/visualization of the demonstration (e.g., test tools, toolkits).
- OpenADR 2.0-compliant clients
- Gateways implementing the OpenSEG specification.

The D2G Lab also hopes to demonstrate Open Smart Energy Gateway (OpenSEG) devices to help determine the value of providing real-time energy consumption data to the customers through smart meters.

The Technical Advisory Group (TAG)

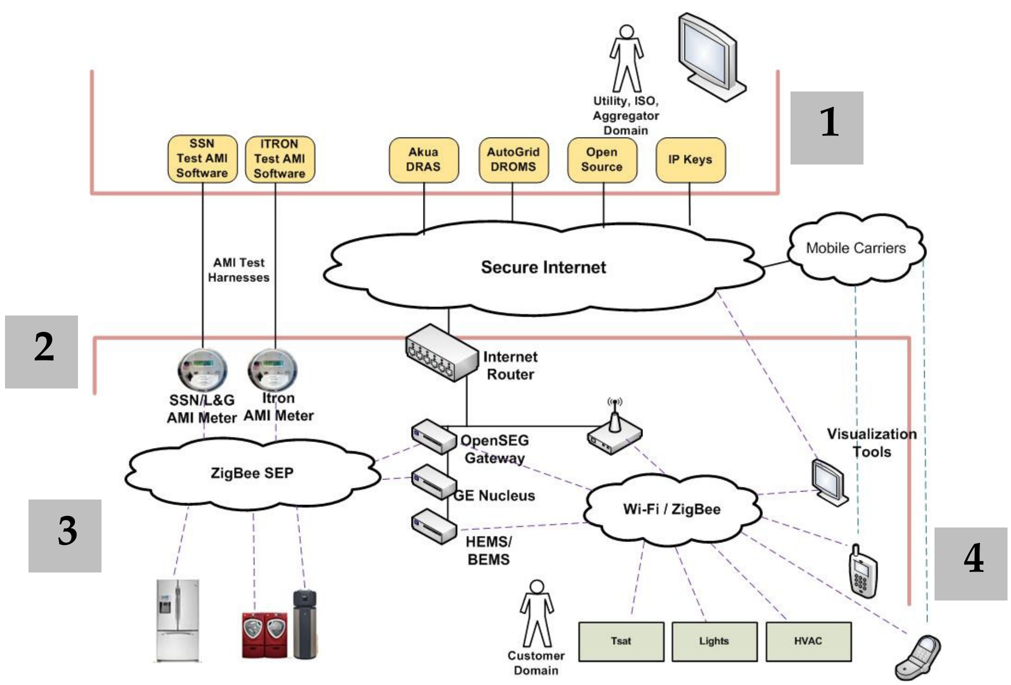
To provide guidance, improve communications, and technology transfer, we formed a TAG. Members review the D2G Lab draft plans and discuss the research and demonstration outcomes. B lists the organizations and individuals that served as TAG members. In addition to the TAG review, the Demand Response Research Center (DRRC) provided regular updates on the D2G Lab's equipment/ device installation status and research and demonstration plans to the Energy Commission. These D2G Lab updates were part of regular calls, visits, and monthly reports. A full list of visitors to D2G Lab during Phase 1 of its operations is shown in Appendix C.

CHAPTER 3.0: Test Environments and Equipment

The D2G Lab space is housed on site at LBNL, and the test environments are positioned to leverage ongoing LBNL activities such as those at DOE's Facility for Low Energy eXperiments in buildings (FLEXLAB) (Schetrit 2012). This proximity allows the D2G Lab to provide a larger platform to demonstrate DR integration with building energy-efficiency technologies. Most of the D2G Lab equipment was donated by vendors or loaned from them. Figure 2 below shows the communication architecture for test environment for the D2G Lab. The architecture applies to commercial, industrial, residential, and distributed energy resources. The salient features of this architecture consists of the following:

1. A demand-side interface to external systems such as vendors' OpenADR servers, including the AMI and other software applications.
2. External systems that use communications such as the Internet to talk to edge devices such as meters, gateways with OpenADR and ZigBee Smart Energy Profile (SEP).
3. End-use clients using different wired/wireless communication technologies to manage end-use loads such as appliances, thermostats, lighting, HVAC, and more.
4. Visualization of energy use and DR information on computers and smart devices.

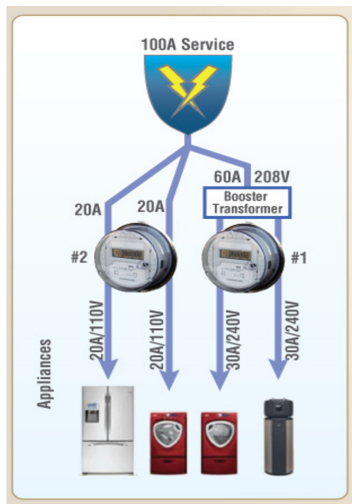
Figure 2: Planned D2G Lab Communication Architecture for Test Environment



(**Legend:** SSN – Silver Spring Networks, AMI – Advanced Metering Infrastructure, DRAS – Demand Response Automation Server, DROMS – Demand Response Optimization and Management Server, L&G – Landis+Gyr, SEP – Smart Energy Profile, OpenSEG – Open Smart Energy Gateway, HEMS – Home energy management system, BEMS – Building Energy Management System, Tstat – Thermostat, HVAC – Heating Ventilation and Air Conditioning.)

For the setup of the smart meters, appliances, lighting, plug-load, and thermostat technologies, and their related network communication and security architecture, LBNL selected an existing laundry room in the Berkeley Lab Guest House to provide the test bed. Two separate circuits were set up in the laundry room to provide power to the GE smart appliances. The communicating appliances include a refrigerator, clothes washer and dryer, and a heat-pump water heater (HPWH). The refrigerator and clothes washer are set up on a 110-volt (V), 20-ampere (A) circuit along with a provision to install a dedicated smart meter to monitor this circuit. Since the clothes dryer and HPWH require 220 V, a booster transformer was installed, along with an Itron smart meter to collect electric consumption readings from this circuit. Figure 3 illustrates the electrical distribution circuits.

Figure 3: D2G Lab Electrical Distribution Circuits



For Phase 1, a variety of equipment/devices and software were used for demonstration and for integration with OpenADR and other standards. Table 4 below summarizes the equipment, vendors, and description of the activities.[4]

Table 4: Summary of Equipment Tested at the D2G Lab

Equipment Type	Demonstration Type and Description
Gateway/Relay	Integrate DR signals with simple relay, direct digital control (DDC), legacy systems.
1.0 Open Source Toolkit Demo	Virtual Machine interface to display devices integrated with end-use devices, strategies, and DR programs.
OpenADR Server (DROMS-RT)	DRAS interface to display devices integrated with end-use devices, strategies, and DR programs.
Thermostats, USNAP	OpenADR Client interface to thermostat and light-emitting diode (LED)

[4] Equipment either received or committed at the end of 2012. Additional equipment is anticipated over the entire operation period.

(Universal Smart Network Access Port) modules, LED Lights	ballasts with Wi-Fi communication and smart devices.
OpenADR Server	DRAS interface to display devices integrated with end-use devices, strategies, and DR programs.
Washer, dryer, water heater; refrigerator.	Residential appliances interfacing with gateways, smart meters, and standards such as OpenADR and SEP 1.0.
Electric Vehicle Charger	Interfaces to DRAS and DR strategies that an EV can use in response to a DR/price signal.

This equipment and these devices were used for the following specific test environments and resulting demonstration activities. Chapter CHAPTER 4.0: Phase 1 Demonstration Activities provides the actual demonstration activities for Phase 1, the control sequence that was executed, a description of the D2G Lab infrastructure supports it, and the test results.

OpenADR 1.0 Open Source Toolkit and Commercial Servers

For Phase 1, the OpenADR 1.0 open source toolkit was made available to public. To date, the DRRC has over 3,500 registered users interested in the toolkit. It was installed at the D2G Lab for demonstration and aiding research. The toolkit, along with similar commercial vendor server implementations, are an important element of research and education to key stakeholders. They also show the usefulness of an open standard to provide multiple instances of server implementations and interoperability of clients. To reduce the capital and operating cost, and for ease of management, the D2G Lab utilized Virtual Machine (VM) services.

In Phase 2, we will install OpenADR 2.0 clients based on the formal standard to connect to different end-use devices, servers, and equipment for research and demonstration. This will allow seamless integration of end-use devices with different servers that provide Auto-DR services using the same OpenADR client and underlying DR strategies. We will also use the larger FLEXLAB visualization space to showcase the technologies and their ability to integrate with OpenADR servers.

Residential Appliances and HAN Integration

For Phase 1, we installed and tested the residential appliances (by GE), the Itron OpenWay meter, and gateway devices, to study residential appliance and Home Area Network (HAN) integration. The GE appliances included a clothes washer and dryer, refrigerator, heat pump water heater, and Nucleus gateway, which is a wireless communication hub for the appliances and smart meter. The meter and Nucleus gateway were “binded” to allow communications. The meter used Itron development software to communicate using the ZigBee Smart Energy Profile (SEP) 1.0. The setup allowed DR events to be initiated and verification of the appliances’ responses. Different visualization modes (e.g., browsers, iPad Apps) were used to demonstrate the DR event and responses. The use of particular end-use equipment/devices and DR strategies will depend on the type of DR opportunity (utility and/or ISO) and the ability of different demand resources to respond to day-ahead and/or day-of (real-time) pricing.

The Phase 2 plans involve using either Itron or SilverSpring smart meters and investigating their ability to use the DR commands over Automated Metering Infrastructure (AMI), through the meter and, ultimately, to GE appliances. We intend to work with GE staff to integrate an OpenADR 2.0 client into a Nucleus gateway platform. We will then test the ability of different OpenADR 2.0 servers to connect to the Nucleus client and receive DR signals. We will verify that appliances respond properly to Nucleus reformatted OpenADR events. Following this, we will work with utilities to investigate the translation of OpenADR events into appropriate AMI messages and test their transmittal through AMI and Nucleus infrastructure to appliances.

HAN Installation and Device Deployment Experiences

As described above, Phase 1 included installation and deployment of multiple HAN devices into a test bed environment. This activity gave us an opportunity to evaluate the level of design "maturity" in these devices and to better understand how they might be integrated into the residential environment. As expected, data communications played a central role in this evaluation. We observed issues in two communication network areas.

- Several problems were seen in the open IP-based communications (e.g. WiFi, Ethernet) used to communicate between HAN devices, notebooks and cloud-based servers.
- We also encountered problems in the private ZigBee SEP 1.0 communications paths used by some HAN devices to communicate with appliances and Smart Meters.

While all issues were ultimately resolved, there are several "lessons learned".

Several devices use variations of the IEEE 802.11 networking protocol to communicate with user computers (e.g. notebooks) and cloud-based servers. Since these protocols are well established and widely used, robust communications performance and reliance on commonly used network provisioning procedures was expected. While this was generally true for devices using wired Ethernet media, there were occasions when some devices based on WiFi-media failed to perform as expected. Since the computing platforms in these HAN devices have limited hardware and software resources, they lack many of the diagnostic capabilities typically found in IT devices. As a result, it was difficult to differentiate between network communications issues and possible device hardware failures. Ultimately, we determined that, within out laboratory, our HAN test bed site was a far more active WiFi environment than device designers anticipated. While these HAN devices were extensively tested in WiFi environments that mimicked a simple residential installation with a single WiFi access point, they could be confused when presented with a more complex wireless environment with multiple, overlapping wireless networks. Such "rich" wireless environments are common in apartment building and corporate/commercial settings. And, while almost all IT equipment (e.g. laptops, printers, etc.) successfully establish and maintain network connectivity in such environments, the inability of some HAN devices to perform correctly indicates one or more incorrect assumptions about the simplicity of real-world HAN environments and a lack of sufficient device testing to eliminate such problems.

Several of the HAN appliances under evaluation used the ZigBee SEP 1.0 networking protocol to communicate between appliance controllers and SEP 1.0 equipped Smart Meters installed at the test bed site. Deployment of SEP-based devices into the HAN environment is still a relatively new activity and we anticipated difficulties in properly provisioning these HAN devices and having them "bind" to the appropriate ZigBee network coordinator (e.g. Smart Meter). In practice, we encountered a number of problems, including:

- Incomplete documentation,
- Devices labeled with incorrect network install codes and
- Devices configured with incompatible firmware versions.

While all of these problems were ultimately addressed, the level of vendor effort required to achieve a functioning system was substantial and, in some cases, unlikely to be sustainable in a larger production environment. In ongoing discussions, vendors generally agreed with this observation.

It is worth mentioning that, in our test bed setting, we were able to interact directly with our ZigBee equipped Smart Meter and diagnose meter provisioning problems directly. In many cases, this allowed vendors to diagnose and address meter-related problems quickly. However, in the absence of such local capabilities, we would be dependent on local utility personnel investigate problems and, in turn, relay that information back to vendors for their interpretation. Our ability to interact directly with the Smart Meter was, and is, an essential part of creating such a HAN test bed. We do, however, have some concerns about how trouble-free HAN device deployments will be in real world conditions where Smart Meter access is more tightly constrained.

Lastly, we had an opportunity to evaluate data access methodologies implemented by HAN device vendors. Most of the HAN devices installed in the test bed are capable of measuring appliance energy consumption as well as overall operation. Once internalized within the device, vendors commonly aggregate this data and export it to a centralized cloud-based server where it is stored for possible later use. These uses include simple value monitoring, complex vendor analytics and direct access/use by customers. As researchers, it is always desirable to have direct access to data and to the metadata that describes the underlying semantics of those measurements. Therefore, it was surprising to see that, while some vendors allowed direct access to and export from server data bases, others had no user mechanism for accessing and exporting device data. In the latter case, the only possible customer view of collected data was that presented to users by vendor interface programs. Detailed values could only be obtained by "scraping" html web pages for pertinent data – a highly error-prone technique. And, in all cases, there was no available metadata that described the details (time schedule, implicit averaging, etc.) surrounding the measurements themselves. While it can be argued that most HAN device customers will only want to see processed data presented in an understandable form, a research test bed requires access to unprocessed data. It was, and continues to be, surprising that such access is not commonly available.

OpenADR Technologies, Systems, and Strategies for End-Uses

For Phase 1, the D2G Lab included OpenADR 1.0 client devices used in California DR programs. End-use devices with clients were integrated with different servers to understand the DR strategies that a customer can take in response to a DR signal. The devices include the Client and Logic with Integrated Relay (CLIR), thermostats and LED lighting systems (by Cloudbeam), and plug-load controllers with OpenADR clients. Such devices converted OpenADR signals to simple relays and mapped prices to simple modes such as Normal, Moderate, and High.

For Phase 2, the D2G Lab will be expanded to include additional end-use devices and their integration with varied end-uses and DR programs, including robust implementations of OpenADR 2.0 standard. Examples of clients include building control systems (e.g., Honeywell, Siemens, Johnson Controls, Automated Logic Corp.), EV chargers, wired/wireless systems, lighting ballasts/controls, and integration with building systems.

Electric Vehicle Charger

For the Phase 1 activity, the EV Charger was used with a “test” load to represent a battery and resistive load to discharge it. The EV charger (by Coulomb Technologies) was used for OpenADR integration and simple response strategies. The D2G Lab demonstration activities included understanding how an OpenADR utility/ISO operator can schedule DR events in which charging level will reduce.

For Phase 2, we will consider open programming interface to ChargePoint™, a nationally deployed EV charging management and billing system, and its integration for DR strategies for an EV.

DR and Auto-DR Simulation Systems

For Phase 1, we installed and conducted visual demonstration of the DR Quick Assessment Tool (DRQAT), used for simulation, to determine how it is used to estimate load shed, using varied strategies for commercial buildings. This gave users an idea of available tools for DR simulation and how one could install and use them.

For Phase 2, the D2G lab will consider improving the visualization of DRQAT integration with building control systems and energy simulation tools to better predict and estimate demand savings potentials.

Industrial, Agriculture, and Water Systems

For Phase 1, the D2G Lab had planned to include a refrigerated warehouses simulation where the DRAS sends a DR event signal to a Programmable Logic Controller (to simulate an industrial setting as opposed to residential/commercial) that then controls a thermostat with an LED display. This DR event would result in the setpoint being raised. However, as suggested earlier, this demonstration is now scheduled for Phase 2.

Phase 2 will also include an agricultural irrigation simulation. The equipment is likely to comprise a simulated soil and plant layout; an aquarium water pump; a soil moisture adequacy sensor/selector, and a relay. The aquarium pump adds water unless there is a "DR event" and the soil has adequate moisture, in which case the relay shuts off the pump.

CHAPTER 4.0: Phase 1 Demonstration Activities

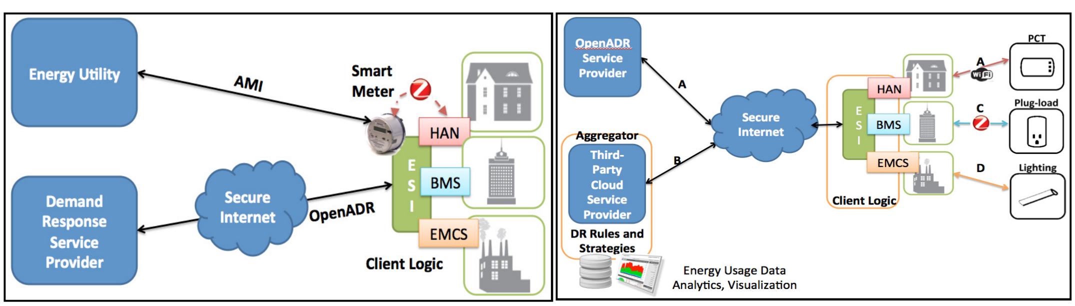
The D2G Lab initially was set up in LBNL's Building 90 (B-90) with a separate dedicated space for residential appliances at the Berkeley Lab Guest House. However, the B-90 space will be integrated with the larger Facility for Low Energy eXperiments in Buildings (FLEXLAB) development to include additional DR test-bed and data visualization systems during the phase 2 of operations. The demonstration activities described in this chapter are based on key interoperability concepts for DR communications.

Interoperability Framework

The interoperability concepts for the D2G Lab were based on the interoperability framework that allowed the OpenADR communications (of servers and clients) to be structured for current DR markets (centralized and point-to-point communications) and for future DR markets (de-centralized communications) to allow energy transactions and customer participation in multiple markets.

Figure 4(a), on the left, shows the current scenario of point-to-point communications between the energy utility and the customer (end uses). The modes of communications are either the AMI or through external channels, such as the Internet (e.g., OpenADR). Here the customers have direct relationships with their DR service providers and their supported DR programs and markets. Figure 4(b), on the right, shows a decentralized architecture, where the DR communications can be decentralized and allow customers to participate in one DR market and/or service provider or multiple DR markets and/or service providers, including the participation from third-party cloud-service providers and aggregators. In both cases, the Energy Services Interface (ESI) acts a demarcation point for what is owned by the service provider and the customer. Both these Auto-DR communication and interoperability concepts were considered at the D2G Lab and formed the basis of demonstration.

Figure 4 (a), 4 (b): Current and Future DR Communication Interoperability Concepts



(**Legend:** AMI – Automated Metering Infrastructure, ESI – Energy Services Interface, HAN – Home Area Network, BMS – Building Management System, EMCS – Energy Management and Control System, PCT – Programmable Communicating Thermostat, A = OpenADR, B = Proprietary, C = ZigBee SEP 1.x, and D = DALI or other lighting and/or HVAC control protocols)

Demonstration Activities

This section describes the specific demonstration activities and results of tests from Phase 1 activities. Table 5 describes the five demonstration areas that were part of the D2G Lab's Phase 1 activities. The areas also list the initial list of solution providers or vendors that participated in these activities. These demonstration areas are described in subsequent sections.

Table 5: Demonstration Areas and Partners

Demonstration Area	Partners
1. Residential Appliances, Thermostats, Plug-load Meters, and HAN.	GE, Cloudbeam, Radio Thermostat, NEST, Itron, SilverSpring Networks
2. OpenADR Technologies and Auto-DR Systems for End Uses and Strategies.	Akuacom, AutoGrid
3. Lighting Controls, Communication, and Technologies	Lunera and NEXT Lighting, Cloudbeam
4. Vehicle to Grid (V2G) and Electric Vehicle Chargers	Coulomb Technologies, Auto-Grid
5. Analytics and Visualization	GE, Cloudbeam, Akuacom, AutoGrid

A detailed description of all the software and hardware demonstrations, along with their communication technologies and key features, are presented in Appendix D.

1. Residential Appliances, Thermostats, Plug-Load Meters, and HAN

Four smart appliances and a communicating thermostat from General Electric (GE) are installed and operated at the Berkeley Lab Guest House laundry room. These appliances communicate using the GE Nucleus Home Area Network (HAN) Gateway. The Nucleus has a Wi-Fi radio and two ZigBee SEP 1.x radios. One ZigBee radio communicates with the HAN radio on a smart meter, while the other ZigBee radio communicates with GE smart appliances. The Nucleus can receive simple prices or shed signals from the utility AMI through the smart meter or from an external (non-OpenADR) server over Wi-Fi. At present, the Nucleus is configured to the Itron smart meter located in the laundry room, which measures the energy use of the dedicated circuit on which the clothes dryer and water heater run. A separate dedicated circuit for the refrigerator and clothes washer is currently unmetered, but a socket has been installed in case another interval meter is to be tested in this space. Figures D-1, D-2, and D-3 in Appendix E provide typical power draw curves for the washer, dryer, and refrigerator, respectively. Table 6 below provides a summary of this demonstration.

Table 6: Summary of Residential Appliances and HAN Gateway

Equipment	Functions	Sector	Communication Technologies	Status
1. Washer 2. Dryer 3. Refrigerator 4. Water Heater 5. Thermostat 6. In-Home Display (IHD) 7. GE Nucleus 8. Smart Meters	DR modes, communication interfaces to smart meters, data analytics, security (OpenSEG)	Residential	ZigBee, Wi-Fi, Ethernet	Installed and operational
Key Features 1. Energy consumption data and analytics visualization via Web browser and iPad/iPhone App; demonstration test bed for appliance integration with the grid 2. Plug-load meters installed for 10-second frequency data and 1-minute averaged visualization (except water heater) 3. Although the water heater data can respond to DR signals, it is not capable to report its real time power consumption via the GE Nucleus gateway.				

The Nucleus provides energy consumption information at five-minute granularity, which can been visualized on a GE In-Home Display (IHD), a computer, or a mobile device. The DR modes and functions of the GE Smart Appliances can be demonstrated by simulating a DR event by creating a custom-pricing cluster in the Nucleus application, as shown in Figure 5.

Figure 5: User-Defined Price Cluster (a) Example of Rate Levels, and (b) Critical DR Event

a

Rate Level	Period Range	Rate
Low	12:00 AM - 6:43 PM	0.1 $/kWh
Medium	6:43 PM - 7:00 PM	0.2 $/kWh
High	7:00 PM - 10:47 PM	0.3 $/kWh
Critical	10:47 PM - 12:00 AM	0.4 $/kWh

b

Rate Level	Period Range	Rate
Low	12:00 AM - 6:43 PM	0.1 $/kWh
Critical	6:43 PM - 7:00 PM	1.0 $/kWh
Low	7:00 PM - 7:45 PM	0.1 $/kWh
Low	7:45 PM - 12:00 AM	0.1 $/kWh

The GE Nucleus interprets the pricing cluster on the left into Low, Medium, High, and Critical modes based on relative difference between the prices from the lowest price. The pricing cluster on the right was manually entered using the Nucleus PC application to simulate a fictitious "critical" demand response event and transmitted to appliances over a ZigBee SEP 1.x wireless link. The appliances are pre-programmed with responses to each mode shown in Table 7. All the DR Strategies shown in Table 7 use price level as a DR trigger. The corresponding demand reductions are summarized in Table 8.

Table 7: Pre-Programmed DR Strategies for GE Appliances

	Rate Level			
Appliance	**Low**	**Medium**	**High**	**Critical**
Washer	Normal Operations and no reaction to pricing information	Normal operations and no reaction to pricing information	In High mode the start of the cycle will be delayed. Cold wash recommended if manually overridden.	In critical mode the Duty cycle wash and heater are reduced by 50%
Dryer			"EP" (Energy Profile) on display. Delay start, recommend reduced heat (Energy Saver) if you override. If running, complete cycle in reduced heat mode (Energy Saver).	The heater power is reduced to 0% for 20 minutes.
Refrigerator			Will raise freezer temp by 5 degrees and put the refrigerator in delay defrost mode. Turbo cool feature is disabled.	Critical mode would disable the electric sweat heaters.
Hybrid Electric Water Heater		"Eco eHeat Mode" is displayed on the screen. The Calrod electric heater is disabled.	Lower setpoint to 110°F. Will display "Eco eHeat Mode" on the screen.	Lower setpoint to 100°F. "Eco eHeat Mode" on display.

Table 8: Power Reduction in Various DR Modes

Appliance	Low Rate Level	High Rate Level		Critical Rate Level	
	Power (W)	Power (W)	% Load Reduction	Power (W)	% Load Reduction
Washer	360	220	39%	60	83%
Dryer	5000	1500	70%	305	94%
Refrigerator	50	30	40%	15	70%

Note: The washer, dryer, and refrigerator do not reduce load for "Medium" rate level. Since the water heater does not have energy reporting capability, the D2G Lab team could not measure its demand reduction in various price mode levels. Unlike the other appliances that can be plugged to a wall socket, the water heater was directly wired in, making it difficult and expensive to install external power monitoring equipment.

Communicating Thermostats

The D2G lab used several communicating thermostats for the demonstration. Each thermostat supports one or more communication standard, including Z-Wave, ZigBee SEP 1.x, OpenADR 1.0, and Wi-Fi. The GE Thermostat supports ZigBee SEP 1.x and receives DR signals from the

Nucleus device. The communicating thermostat from Radio Thermostat Company of America Company (RTOCA) is equipped with a Cloudbeam's OpenADR 1.0 USNAP module. This thermostat is capable of receiving OpenADR signals from commercial OpenADR server. The D2G Lab also includes NEST Wi-Fi thermostat. The ZigBee radio in the NEST thermostat can be turned on to communicate with a HAN gateway or a smart meter and respond to DR signals. The thermostats shown in Figure 6 can be controlled from a Web browser or a mobile app.

Figure 6: Thermostats, Mobile Apps, In-Home-Displays, and Analysis

Additionally, an OpenADR 2.0a-compliant Z-Wave HAN gateway was installed. This gateway is capable of translating OpenADR 2.0 messages from any commercial OpenADR 2.0 server into Z-Wave messages and triggering a DR strategy pre-programmed in the Z-Wave thermostat. This is good demonstration of interoperability of smart grid standards and grid integration with a HAN technology. Table 9 presents a brief summary and key features of this demonstration area.

Table 9: Summary of Communicating Thermostats Demonstration

Equipment	Functions	Sector	Communication Technologies	Status
1. Communicating Thermostats 2. Z-Wave Gateway with OpenADR 2.0a	Temperature set point adjustments	Commercial, Industrial, Residential	ZigBee, Z-Wave Wi-Fi, OpenADR 1.0, 2.0a	Installed and operational
Key Features 1. Web application for creating a DR strategy for the communicating thermostats 2. Auto-DR demonstration and IHD data visualization 3. Energy analytics and download using computer and iPhone App 4. Interoperability demonstration of OpenADR 2.0 and Z-Wave Gateway				

Smart Plug Load Meters

To enhance demonstration and visualization capabilities of the GE smart appliances, OpenADR 1.0-enabled smart plugs from Cloudbeam were installed on all the appliances except the GE heat pump water heater. Although the GE smart appliances had energy-reporting and visualization capabilities at a 5-minute refresh rate, the higher data granularity and update frequency of the Cloudbeam smart plugs was a key reason for smart plug installation. The smart plugs are capable of collecting data at 10-second frequency and pushing it to the Cloudbeam's database for Web-based analytics and historical energy consumption trending. Prior to the installation of the smart plugs, D2G lab visitors had to wait for five minutes to visually see the decrease in energy consumption once the DR modes were triggered. The smart plug can be turned on and off from the Cloudbeam's portal or from the iPad app.

In the current demonstration at the D2G Lab, the smart plugs are configured to receive OpenADR signals from Akuacom's Client Development Portal (CDP) DRAS. They have also been tested with AutoGrid's DROMS. Figure 7 shows the Cloudbeam smart plug and the control widget. Table 10 provides a brief summary and lists key features of this demonstration.

Figure 7: Cloudbeam Smart Plug and Web-Based Control Widget

Table 10: Summary of Smart Plugs Demonstration

Equipment	Functions	Sector	Communication Technologies	Status
1. Cloudbeam 2. Smart plugs 3. DRAS	Energy Monitoring Programmable	Commercial, Industrial, Residential	Wi-Fi, OpenADR 1.0	Installed and operational
Key Features 1. Smart plug consists of a Cloudbeam OpenADR 1.0 client with Wi-Fi communication module. 2. Using the client interface of Akuacom's Client Development program DRAS to manually trigger a DR event and turn off GE appliances 3. Plug load meters primarily for data extraction 4. Programmable with a 7-day on/off schedule with mobile app-based control 5. Highly granular real-time and historical energy consumption information for the GE smart appliances				

2. OpenADR Technologies and Auto-DR Systems for End-Uses and Strategies

The D2G Lab staff conducted DR automation tests using commercially available OpenADR servers from Honeywell, Akuacom, and AutoGrid. The smart plugs, LED lighting, and controllers, thermostats, and other OpenADR devices are configurable to receive OpenADR 1.0 signals from Akuacom or the AutoGrid OpenADR server and trigger the pre-programmed strategies. The signals include simple modes such as Normal, Moderate, and High or dynamic pricing signals (integer values). The AutoGrid OpenADR server is agnostic of the communication protocol used by end-use devices.

Lawrence Berkeley National Laboratory is beginning work on the installation and demonstration of an OpenADR 2.0 server and test tool (used for certification). Figure 8 shows the OpenADR 2.0 architecture, which is based on the OpenADR 1.0 client-server architecture. The clients are called Virtual End Nodes (VEN), to signify end points or customers that receive DR information, and servers are called Virtual Top Nodes (VTN), to signify servers or service providers sending the DR information. OpenADR can exist within the centralized and de-centralized markets. Table 11 presents a brief summary and key features of this demonstration (OpenADR Alliance 2013).

Figure 8: OpenADR 2.0 Architecture for Service Providers and Customers

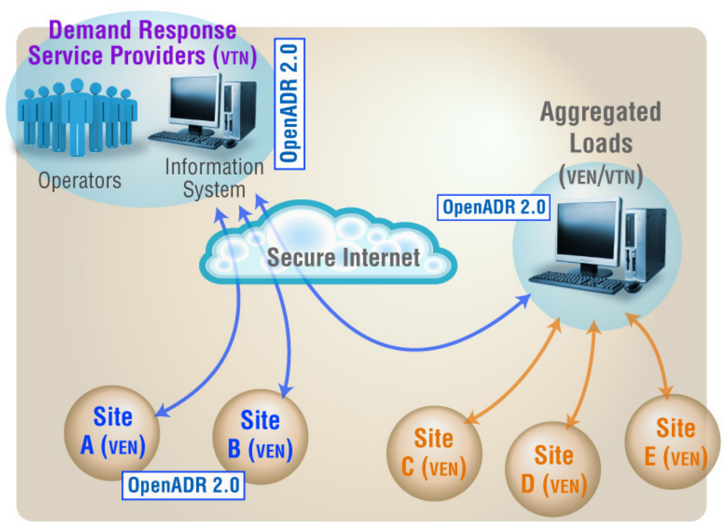


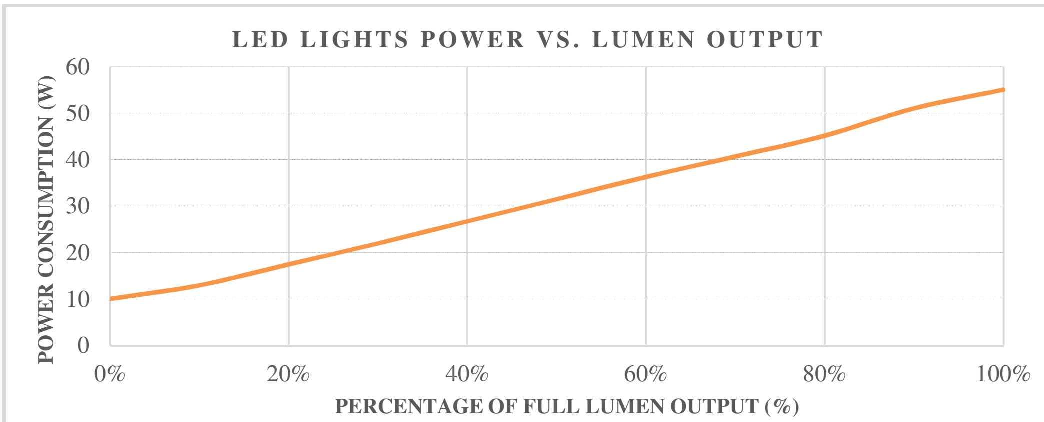
Table 11: Summary of OpenADR Servers Demonstration

Equipment	Functions	Sector	Communication Technologies	Status
1. Akuacom DRAS 2. AutoGrid DROMS	DR Server	Commercial, Industrial, Residential	OpenADR 1.0	Installed and operational
Key Features 1. Using the client interface of Akuacom's Client Development program DRAS to manually trigger DR strategies (DRAS Facility Manager login). 2. AutoGrid DROMS can communicate with both OpenADR and non-OpenADR devices such as NEST thermostats and Coulomb EV chargers. 3. AutoGrid DROMS is a fully functional server that can be used to schedule time- and location-based DR events.				

3. Lighting Controls, Communication, and Technologies

The D2G lab's demonstration at the Berkeley Lab Guest House laundry room is equipped with state-of-the-art energy-efficient LED lighting fixtures. The OpenADR 1.0 client is embedded in the Wi-Fi communication module, which is integrated with the driver of the 4" LED light fixtures. These lighting fixtures are capable of dimming and are fully programmable for a seven-day operational schedule. Each fixture can communicate with an OpenADR 1.0 server and respond to pre-programmed DR strategies independently or as a group. When the fixtures receive the DR signal, they can either dim to a predefined brightness level (expressed as a percent of full lumen output) or be turned off completely. After the DR event, the lights return to normal state of lumen output. Figure 9 shows a linear correlation between power consumption and brightness level of the LED lights installed at the D2G lab.

Figure 9: Correlation between Power and Lumen Output of LED Lights at the D2G Lab



The technologies used in this demonstration are commercially available as retrofit kits for existing T8 fixtures, which are commonly found in commercial and industrial facilities. Table 12 presents a brief summary and key features of this demonstration.

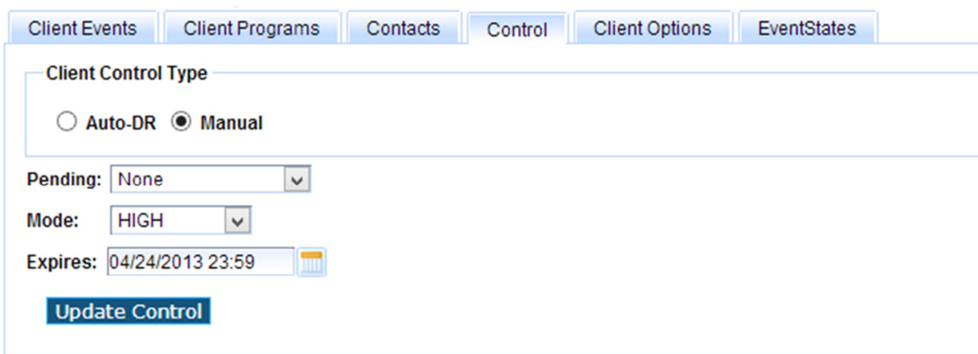
Table 12: Dimmable Lighting Technologies Demonstration

Equipment	Functions	Sector	Communication Technologies	Status
Dimmable LED lighting fixtures and controllers	Lighting controls, dimming to lower levels in DR modes	Commercial, Industrial, Residential	Wi-Fi, OpenADR	Installed and operational
Key Features 1. Two LED lighting fixtures each consisting of two 4-feet LED lamps, an LED driver, and a Cloudbeam OpenADR client with Wi-Fi communication module. 2. Using the client interface of Akuacom's client development program DRAS to manually trigger a DR event to dim the LED lighting fixtures. 3. Lighting fixtures translate OpenADR message into 0–10 V protocols for dimming. 4. Vendors: Cloudbeam, NEXT Lighting, Lunera				

Using Akuacom's Client Development Portal (CDP) DRAS for OpenADR 1.0, a DR event was triggered by setting the client control type to "Manual" and mode to "HIGH," as shown in

Figure 10. Selecting Auto-DR and clicking "Update Control" would end the test event and allow the devices to return to normal operation.

Figure 10: Akuacom's DRAS Client Control Module



In response to DR signal, each LED fixture responded independently and reduced the lighting levels as defined by the user on the Cloudbeam Web portal. Both LED Fixture 1 and Fixture 2 were pre-programmed to reduce the lighting levels by 70 percent and 50 percent, respectively. When the LED fixture is dimmed to 0 percent brightness, it consumes about 10 watts, which is the power consumed by the LED driver and the embedded Wi-Fi module. When the fixture is turned off, the fixture does not draw any power. At 100 percent brightness, each fixture consumes 55 watts. The results of demand saving for different modes from this strategy are shown in Table 13. Figure D-4 in Appendix D provides a typical power draw curve for an LED fixture.

Table 13: Summary of Power and Lumen Reduction Due to a DR Event

	Normal		Moderate		High	
	% of Full Lumen Output	Power (W)	% of Full Lumen Output	Power (W)	% of Full Lumen Output	Power (W)
LED Fixture 1	100%	55	80%	45	30%	22
LED Fixture 2	100%	55	80%	45	50%	32

4. Vehicle to Grid and Electric Vehicle Chargers

The D2G lab is equipped with a Level II EV Charger by Coulomb® Technologies, connected to the ChargePoint™ network. The EV charger is packaged in a demonstration suitcase for offsite demonstrations. The demonstration includes communications between Coulomb's ChargePoint portal and AutoGrid OpenADR 1.0 DROMS portal. The DROMS portal communicates to the EV charger via a proprietary protocol, which triggers a DR event and delays the charging cycle time. Due to the absence of an actual resistive load (or an EV), the D2G lab team was not able to measure energy and demand reductions resulting from delaying the charge cycle.

In Phase 2, the D2G Lab aims to test similar strategies using OpenADR 2.0 and Open Charge Point Protocol (OCPP). A permanent installation of the EV charger for carrying out testing and demonstration using actual electric vehicles is also being considered. Figure 11 shows a simple communications architecture of the EV Charger and DROMS portal. Table 14 provides a summary of the EV charger demonstration.

Figure 11: Communication Architecture of the EV Charger Demonstration

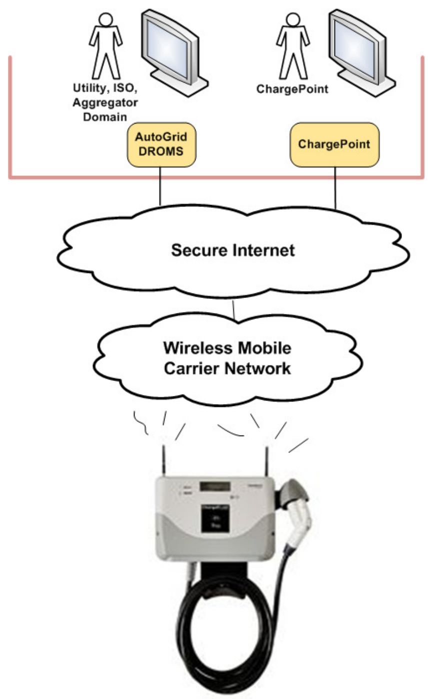


Table 14: Summary of EV Charger Demonstration

Equipment	Functions	Sector	Communication Technologies	Status
Coulomb Charger (CT500 Level II)	EV/PHEV Chargers	Transportation	CDMA, GPRS, LAN	Installed and operational
Key Features 1. The EV charger used with a "test" load to represent a battery and resistive load to discharge it. 2. Utility/ISO-scheduled DR "events" result in reduced charge levels. Uses open Application Programming Interface (API) to ChargePoint, a nationally deployed EV charging management and billing system. 3. Ability to participate in DR programs by integrating with AutoGrid DROMS. 4. The EV charger will actually display a message on the screen. 5. The EV charger complies with SAE J1772 plug-in electric vehicle charging standards.				

5. Analytics and Visualization

One of the key objectives of the project is to show real-time and historical energy consumption and DR results data from demonstration activities at the D2G Lab. Due to the diversity of vendors and technology offerings, the capabilities of each device and visualization platform are different. To successfully demonstrate the DR function of each end use and observe the results of analysis and amount of load shed achieved in real-time from a DR event requires granular data and advanced visualization technologies. The data can be accessed via a Web portal (cloud), applications on smartphones or tablets, or on an IHD.

Table 15 provides a summary of all the software visualization tools currently available at the D2G Lab. Most of them provide basic analytics capabilities and data export functionality (CSV format) for advanced analysis.

Table 15: Summary of Visualization Tools at the D2G Lab

Equipment	Data Points	Granularity	Visualization	Visualization Refresh Rate	API Access
Smart Meter	Energy	10 seconds	In development by DRRC	Real time	Yes
GE Nucleus (Appliances)	Energy, Demand,	15 seconds	PC Software, iOS App	5 minute	No
Smart Plugs	Energy, Demand, On/Off status	5 seconds	Web Browser, iOS App	1 minute	Yes
Wi-Fi Thermostats	Temperature, On/Off Status	10 seconds	Web Browser, iOS App	1 minute	Yes
LED Lights	Power, On/Off Status	5 seconds	Web Browser, iOS App	1 minute	Yes
EV Charger	Energy per Charge Cycle	5 minutes	Web Browser	15 minute	Yes

CHAPTER 5.0: Conclusions and Next Steps

The findings from D2G Lab has provided technology transfer and important insights to key stakeholders that demonstrations are effective means to show R&D concepts and to identify new R&D and deployment areas. The demonstration test bed is also useful for conducting research, identifying empirical evidence, and validating the findings and conclusions that benefit the wider grid integration community.

The key findings from the demonstrations described in Chapter 4 are as follows:

- The Appliance Lab assisted LBNL research on evaluation of the maturity of home area networks and on identifying the options to provide customer data access and grid integration functionalities, including OpenADR and AMI networks and SEP 1.x communications. We found that the design "maturity" in these devices has been problematic. Issues we experienced included incomplete documentation on how to configure the devices, incorrect network install codes and devices configured with incompatible versions of firmware.
- Open standards that have a compliance and certification framework play a role in information interoperability. Also, an appropriate architecture provides customer benefits in low-cost automation infrastructure and eases DR program participation.
- Data storage, trending, and visualization are required to validate DR and technology performance. The visualization screens and those customized for the D2G Lab analytics can assist in measurement and verification of DR shed and to understand the effectiveness of equipment/device response strategies.

The lighting controllers, thermostats, and plug-meters demonstrations are set up, however, the data is yet to be analyzed for research evaluations. These end-uses show innovative use of OpenADR to achieve interoperability and use of an OpenADR 1.0 client at the device level and allowing customers the choice to easily program their response strategies for DR.

Next Steps

The next steps for the D2G Lab for the second year of operations (Phase 2) will be to continue the existing demonstrations and conduct new ones, to provide a suitable grid integration research and demonstration framework for the FLEXLAB, and to implement a flexible data storage and mining platform to conduct research.

Integration with the FLEXLAB

To provide broader links to energy efficiency and DR and address the grid integration requirements, the D2G Lab demonstrations in Phase 1 and those planned for Phase 2 will be integrated with the FLEXLAB. The FLEXLAB provides a set of tools to allow research on building components and systems design and control to support the DOE Energy Efficiency and Renewable Energy (EERE) grid integration initiatives. Improving the flexibility of electric loads in buildings will allow the electric grid to be more cost effective as more intermittent renewables are used in the supply systems. The DOE has supported the development of transactive controls that provide responsive demand assets. Building loads in FLEXLAB can be controlled to bid into grid signals such as dynamic pricing. Table 16 shows the benefits of D2G Lab use cases for the FLEXLAB to test capabilities with various performance parameters and benefits:

Table 16: FLEXLAB Test Capabilities and Performance Parameters and Benefits

Test-Bed Capabilities	Performance Parameters and Benefits
Lighting systems; Fixture power and demand	System energy use and peak demand; Energy savings relative to non-controlled 1980s retrofit base-case in twin cell.
HVAC control and energy use	Zonal load measurement, hydronic or air conditioning
Robust data acquisition system to accommodate additional instrumentation	Flexibility to integrate experiment-specific measurement hardware with existing test-bed instrumentation
DR automation server and client designs	Client-server capabilities, price and reliability signals, latency testing
Energy and Demand Response Models	EnergyPlus and Modelica to model control strategies, HVAC, lighting, and whole "test-bed" energy use

Data Storage and Mining Platform

As part of the FLEXLAB activity, LBNL is specifying data acquisition systems, which consist of a database (and its relevant user interfaces) and software modules for data collection and real-time analytics. The D2G Lab data is currently being recorded in external databases. Using Web API's data will be extracted from external databases and stored in the FLEXLAB database, which can be queried for control and analysis purposes and for conducting energy-efficiency and grid-integration research. This database repository is intended to accept data streams from different sources (e.g., offsite generated data, other lab facilities, vendor demonstration data) with secure permissions and access rights. The D2G Lab vendor demonstration (e.g., Cloudbeam, GE) will be used to understand these database requirements.

Future Demonstrations and Research Directions

The key future demonstrations (one to two years) for the D2G Lab will include the following to address research needs. These demonstration and research needs were on the basis of the original test environments and equipment plans as described in Chapter 3.

- OpenADR 2.0 compliance process and test tools, clients, and/or server interoperability
- OpenADR interoperability with end uses (e.g., EV chargers, agricultural irrigation), devices (e.g., smart meters), control systems, protocols (e.g., SEP 2.0, ECHONET, BACnet), and networks (e.g., AMI)
- Interfaces for Smart Grid standards, interoperability, communication protocols, security, technologies, data trending, etc.

- Energy use and analytics visualization using browsers and handheld devices
- Interoperable energy management and grid-integrated rooftop unit (RTU) networks using OpenADR and relevant protocols for transactive controls
- Integration of building control systems and components with simulation tools

GLOSSARY

AECOM	AECOM Technology Corporation
AEP	American Electric Power Company
AMI	Advanced Metering Infrastructure
API	Application Programming Interface
Auto-DR	Automated Demand Response
BEMS	Building Energy Management System
BMS	Building Management System
BPA	Bonneville Power Administration
CDMA	Code Division Multiple Access
CDP	Client Development Portal
CEC	California Energy Commission
CEPRI	China Electric Power Research Institute
CLIR	Client and Logic with Integrated Relay
CPUC	California Public Utilities Commission
CSGC	California Smart Grid Center, Sacramento
CSV	Comma Separated Values
D2G Lab	Demand To Grid Lab
DALI	Digital Addressable Lighting Interface
DDC	Direct Digital Control
DER	Distributed Energy Resources
DOE	United States Department of Energy
DR	Demand Response
DRAS	Demand Response Automation Server
DROMS	Demand Response Optimization and Management Server
DRQAT	Demand Response Quick Assessment Tool
DRRC	Demand Response Research Center

EEB Hub	Energy Efficient Buildings Hub
EERE	Energy Efficiency and Renewable Energy
EIOC	Electricity Infrastructure Operations Center
EMCS	Energy Management Control System
EPIC	Electric Program Investment Charge
ESI	Energy Services Interface
ESIF	Energy Systems Integration Facility
EV	Electric Vehicle
FLEXLAB	Facility for Low Energy eXperiments in Buildings
GE	General Electric
GPRS	General Packet Radio Service
HAN	Home Area Network
HEMS	Home Energy Management System
HPWH	Heat Pump Water Heater
HRI	Honda Research Institute
HVAC	Heating, Ventilation, and Air Conditioning
IHD	In-Home Display
ISO	Independent System Operator
kW	Kilowatt
kWh	Kilowatt-Hour
L&G/L+G	Landis+Gyr
LAN	Local Area Network
LBNL	Lawrence Berkeley National Laboratory
LCD	Liquid-Crystal Display
LED	Light-Emitting Diode
M&V	Measurement and Verification
NEC	Nippon Electric Company

NREL	National Renewable Energy Laboratory
NTT	Nippon Telegraph and Telephone
NV Energy	Nevada Energy
OCPP	Open Charge Point Protocol
OpenADR	Open Automated Demand Response Standard
OpenSEG	Open Smart Energy Gateway
PC	Personal Computer
PCT	Programmable Communicating Thermostat
PG&E	Pacific Gas and Electric Company
PHEV	Plug-in Hybrid Electric Vehicle
PIER	Public Interest Energy Research
PLC	Programmable Logic Controller
PNNL	Pacific Northwest National Laboratory
R&D	Research and Development
RTOCA	Radio Thermostat Company of America Company
RTU	Rooftop Unit
SAE	Society of Automotive Engineers
SCE	Southern California Edison
SDG&E	San Diego Gas and Electric
SEARI	Shanghai Electrical Apparatus Research Institute
SMERC	Smart Grid Energy Research Center
SMUD	Sacramento Municipal Utility District
SSN	Silver Spring Networks
TAG	Technical Advisory Group
TEPCO	Tokyo Electric Power Company
TOU	Time of Use
Tstat	Thermostat

UC	University of California
UCLA	University of California, Los Angeles
USNAP	Utility Smart Network Access Port Alliance
V2G	Vehicle to Grid
VEN	Virtual End Nodes
VM	Virtual Machine
VTN	Virtual Top Nodes
Wi-Fi	Wireless Fidelity
ZigBee SEP	ZigBee Smart Energy Profile

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APPENDIX A:
U.S. Smart Grid Labs

Table A-1 contains a list of known U.S. Smart Grid labs, along with their related areas of research, demonstrations, and testing. Table 2 provides a list of known U.S. Smart Grid labs, along with their related areas of research, demonstrations, and testing. The TAG member provided the names for some of the labs (see Appendix B).

Table A-1: Examples of Key U.S. Labs for Smart Grid Research and Demonstration

Name	Research & Demonstration Areas	Location	Website
California Smart Grid Center, California State University, Sacramento	Security, sensors, home area networks, and transmission and distribution	Sacramento, CA	http://www.ecs.csus.edu/csgc
EnerNex Smart Grid Labs	Communications, power systems, compliance, and metering infrastructure	Knoxville, TN	www.smartgridlabs.com
National Renewable Energy Laboratory Energy Systems Integration Facility (ESIF)	Renewable integration, electric vehicles, appliances, smart meter, storage, and energy management systems	Golden, CO	www.nrel.gov/esi
EPRI IntelliGrid Smart Grid Resource Center	Interoperability, communications, planning, and distributed energy resources (DER)	Palo Alto, CA	http://smartgrid.epri.com
KEMA Smart Grid Interop Lab	Standards and interoperability testing, meters, appliances, EV chargers, performance testing, low-voltage automation devices, and storage	Erlanger, KY	http://www.dnvkema.com/innovations/smart-grids/smart-grid-interop
Pecan Street, Inc.	Storage technologies, appliances, EVs, smart meters, home energy management, and pricing models	Austin, TX	http://www.pecanstreet.org/
University of California, Los Angeles, Smart Grid Energy Research Center (SMERC)	Automation, EV integration, microgrids, distributed resources, renewable integration, and cyber-security	Los Angeles, CA	http://smartgrid.ucla.edu
Pacific Gas & Electric Emerging Technology Lab	Smart meters, HAN radio, (e.g., ZigBee), vehicle charger, and SEP 1.x testing, IHDs, thermostats, and related HAN equipment	San Ramon, CA	http://www.pge.com/smartgrid
Pacific Northwest National Laboratory Electricity Infrastructure Operations Center (EIOC)	Electricity transmission and distribution, real-time grid data, and simulation	Richland, WA	http://eioc.pnnl.gov
Energy Efficient Buildings Hub at the Navy Yard	Modeling and simulation; building energy informatics; intelligent building operations; building energy systems, markets, and behavior; education and training	Philadelphia, PA	http://www.eebhub.org/projects-list/navy-yard-building-661
University of Delaware/NRG Energy eV2g project	Electric vehicle-to-grid capability demonstration with 30 EV cars with bi-directional power flow. The cars participate as an aggregated resource in PJM's wholesale markets.	Newark, DE	http://www.udel.edu/V2G/

APPENDIX B: TAG Members and Organizations

Table A-2 shows the final list of organizations or individuals who accepted DRRC's invitation to serve on the D2G Lab TAG Committee. These members were identified as key stakeholders in advancing DR research and bringing it to the market. Considering the success of OpenADR in the United States, and that California's Smart Grid goals are closely tied to national goals, we have included some key organizations or individuals outside California:

Table B-1: List of Organizations and Individuals that Served as TAG Members

Representative	Organization
Ron Hofmann	CaRon Energy Strategies
Anish Gautam	California Energy Commission (CEC)
Golam Kibrya	California Energy Commission (CEC)
Raquel Kravitz	California Energy Commission (CEC)
David Hungerford	California Energy Commission (CEC)
Steve Ghadiri	California Energy Commission (CEC)
Rob Neenan	California League of Food Processors (CLPF)
Konstantinos Papamichael	California Lighting Technology Center – UC Davis
Aloke Gupta	California Public Utilities Commission (CPUC)
Walt Johnson	DNV KEMA
Aaron Snyder	EnerNex
Matt Wakefield	Electric Power Research Institute (EPRI)
Robert Burke	ISO New England
David Holmberg	National Institute of Standards and Technology (NIST)
Tony Abate	New York State Energy Research and Development Authority (NYSERDA)
Barry Haaser	OpenADR Alliance
Rolf Bienert	OpenADR Alliance
Jonathan Burrows	Pacific Gas and Electric Company (PG&E)
Osman Sezgen	Pacific Gas and Electric Company (PG&E)
Susan Covino	PJM Interconnection, LLC
Carl Besaw	Southern California Edison (SCE)
Vikki Wood	Sacramento Municipal Utility District (SMUD)
Jim Parks	Sacramento Municipal Utility District (SMUD)
Anne Smart	Silicon Valley Leadership Group (SVLG)
Eric Lightener	U.S. Department of Energy (DOE)
Dan Ton	U.S. Department of Energy (DOE)
David Lee	U.S. Department of Energy (DOE)
Rajit Gadh	University of California – Los Angeles
Byron Washom	University of California – San Diego
Roger Levy	Levy Associates

APPENDIX C: D2G Lab Visitors

Over 50 organizations, ranging from national and international research organizations and industry stakeholders, visited the D2G Lab. One of the primary objectives of the D2G Lab is to conduct demonstrations to disseminate the advancement in grid integration technologies and to understand the orientation of the industry. Inputs from some of the key organizations have been instrumental in understanding the industry requirements to define research topics that need to be addressed. Table C-1 below provides a list of all the visitors to the D2G Lab (until May 2013).

Table C-1: List of Key Organizations Visiting the D2G Lab for Year 1.[5]

Public and Research Institutions	Private Companies	Utilities	International
CEC	Aduratech	AEP Ohio	CEPRI, China
Arizona State University	AECOM	Con Edison	Delegation of Regulators, India
BPA	Buro Happold	Idaho Power	Energa, Poland
CPUC	Cascade Energy	NV Energy	HRI, Japan
LBNL	Consortium for Energy Efficiency	Omaha Public Power District	Industrial Manufacturer Association, China
Northwest Energy Efficiency Alliance	Daikin	PG&E	NEC, Japan
NREL	EchoLabs	Portland Gas and Electric	NTT, Japan
Penn State University	Energy Connect	SCE	SEARI, China
PNNL	EnerNOC	SMUD	State Grid Corporation of China
SF Public Utilities Commission	Fujitsu Labs	Union Gas, Toronto	TEPCO, Japan
Tennessee Valley Authority	GE	Xcel Energy	UK House of Commons
UC Berkeley	Honeywell		
U.S. DOE	Itron		
	OpenADR Alliance		
	O'Reilly Media, Inc.		
	Z-Wave Alliance		

[5] The expanded list of acronyms in Table B-1 is included in the Glossary.

APPENDIX D: Hardware and Software Demonstrations at D2G Lab

Table D-1 provides a description, list of communication technologies, and key features of all the hardware that was in demonstration at the D2G lab during the first year of its operation.

Table D-1: Hardware Demonstrations at the D2G Lab

Demonstration	Description	Communication Technologies	Key Features
GE Nucleus	GE's HAN Gateway is capable of communicating with the utility smart meter ZigBee radio. It can collect energy consumption data from GE's smart appliances over ZigBee and display on a PC or mobile device. The GE Nucleus can receive energy prices from the Internet or smart meter AMI network and relay them to the GE appliances and thermostats.	ZigBee SEP 1.0, Wi-Fi, and Ethernet	• Communication with smart meter and appliances • Energy consumption data collection and analytics
GE In-Home Display (IHD)	GE's IHD device communicates with the GE Nucleus and displays time-of-use energy prices and demand response event messages. It also allows users to visualize the historical energy consumption of smart appliances.	ZigBee SEP 1.0	• Small and easy to install • High-resolution color LCD screen • Scroll wheel for navigation
GE Appliances and Thermostats	GE's suite of smart appliances includes a washer, dryer, water heater, and refrigerator. In addition to these, the D2G lab demonstration includes a GE communicating thermostat.	ZigBee SEP 1.0	• Pre-programmed DR modes for appliances • Customizable temperature setpoints for thermostats based on TOU rates • Report energy consumption and usage data to GE nucleus
Cloudbeam Smart Plugs	Wireless smart plugs to monitor, control, and automate plug-in electronic devices. Cloudbeam smart plugs can collect and report energy consumption data every five seconds. These smart plugs can poll any OpenADR-enabled DR automation server every minute and respond to DR signals. Cloudbeam's portal can be used to pre-program a response on/off strategy.	OpenADR 1.0, Wi-Fi	• Highly granular energy consumption data • Does not require additional gateway • Control using PC and mobile apps
NEXT LED Lights (with Cloudbeam Light Controller)	The lighting fixtures installed at the D2G lab include 4' LED lamps, a specially designed dimming ballast, and a Wi-Fi lighting controller developed by Cloudbeam. The Wi-Fi control module allows the	OpenADR 1.0, Wi-Fi	• High-efficiency LED lights and ballast • Built-in OpenADR client • Dimming ballast

	lighting fixture to respond to OpenADR signals and dim to a pre-programmed level. These components are available as a direct retrofit kit to standard T8 fixtures.		• Packaged retrofit kit • 10-second granular data • On/off and dim using PC and Mobile App

Radio Thermostats (with Cloudbeam USNAP module)	Thermostats manufactured by Radio Thermostat Company of America (RTCOA) with a compatible OpenADR-enabled USNAP module developed by Cloudbeam. This thermostat is capable of receiving OpenADR signals and change temperature setpoints based on the pre-programmed strategy.	OpenADR 1.0, Wi-Fi	• 2 hot-swappable USNAP module slots • Compatible with OpenADR, ZigBee, or Z-wave USNAP modules • Control using a PC and Mobile App
Cloudbeam Demonstration Suitcase	The demonstration suitcase includes thermostat, an LED Light, and a smart plug, all connected to a preconfigured Wi-Fi router. This suitcase can be used to conduct off-site demonstrations. Demand response tests can be displayed in real time by triggering an event using a DR automation server from Akuacom or AutoGrid.	OpenADR, Wi-Fi	• All-inclusive demonstration suitcase • Requires an Internet connection to display analytics and cloud access
NEST Thermostat	A programmable communicating thermostat manufactured by NEST. This thermostat has a Wi-Fi radio which allows communication with a NEST cloud platform and mobile app.	ZigBee, Wi-Fi	• High-resolution LED display with intuitive user interface • iOS and Android App • ZigBee radio for smart meter communication • Occupancy and humidity sensors • automated updates over Wi-Fi
Coulomb EV Charger	Coulomb CT 500 Level II EV charger connected to Coulomb's ChargePoint network. This EV charger is capable of receiving demand response signals from AutoGrid's DROMS system and delaying the charging cycle time.	Cellular (CDMA/GPRS)	• AutoGrid's integration of ChargePoint API into DROMS • The user defines the DR strategy in DROMS
OpenADR-enabled Z-Wave Gateway	BuLogics Z-Wave Gateway with OpenADR 2.0 client built in. This gateway can receive OpenADR signals over Wi-Fi, translate them to Z-Wave message, and sent to Z-Wave-enabled devices to achieve load shed. The current demonstration at the D2G Lab includes a Z-Wave gateway, Z-Wave thermostats, and wireless on/off switches.	Z-Wave, OpenADR 2.0, Wi-Fi, Ethernet	• Demonstration of interoperability of OpenADR and Z-Wave standards • Z-Wave is a widely adopted home automation standard with many of products.

Table D-2 provides a description, visualization or accessibility options, and key features of all the software in demonstration at the D2G lab during the first year of its operation.

Table D-2: Software Demonstrations at the D2G Lab

Demonstration	Description	Accessibility	Key Features
Cloudbeam Portal	Cloudbeam's Web portal allows users to control devices and visualize real-time and historical energy consumption trends. It also allows users to program each device with a demand response strategy.	iOS Apps, Web Browser	• Device commissioning • Monitor and control • OpenADR strategy page • Energy analytics
AutoGrid DROMS	The Demand Response Optimization and Management System (DROMS) is a DR automation server with multiprotocol support. It features direct application level communication and control.	Web Browser	• Cloud-based DR server • OpenADR 2.0-certified • Deploy and enroll customers • Supports simple and smart client communication
Akuacom DRAS	The Demand Response Automation Server (DRAS) by Akuacom is at the D2G Lab for DR tests and demonstrations. The DRAD development portal allows same user interface as the production server to be replicated.	Web Browser	• OpenADR 1.0 compliant • Simple set up and Web-based control • Test signals can be sent to simulate DR events
OpenADR Toolkit	The OpenADR 1.0 toolkit was developed and released by LBNL. This tool is currently being demonstrated to simulate a demand response server and client.	Windows OS, development environment	• Codebase with development kit for simple client/server demonstration • Command line tool
OpenADR Compliance Test Suite	Developed by Quality Logic, this tool is used to test the compliance of any OpenADR 2.0 server or client. It is used by Quality Logic to certify OpenADR 2.0 servers and client devices. Several test scenarios have been predefined in the test suite.	Windows OS, development environment	• Developed and executed in Eclipse • Device compliance to OpenADR 2.0 profiles • More than 200 individual test cases
GE Nucleus Software	GE Nucleus PC-based software allows users to monitor and visualize energy usage and TOU price information. This application is used to commission new devices with the GE Nucleus gateway as well as to communicate with a smart meter. This application allows users to choose the TOU price source (smart meter, GE Price server, or user defined). User-defined TOU rates are being used for testing and demonstration at the D2G Lab.	iOS, Windows OS, and Mac Applications	• Intuitive Adobe Air-based applications for Mac and PC • Configurable widgets for personalized user experience • View historical energy consumption • Thermostat programming and control from PC and mobile apps

APPENDIX E: Appliance Load Shapes

The following figures show the power consumption for a 24-hour period of the appliances and lighting fixtures installed at the D2G Lab.

Figure E-1: Power Consumption of the GE Clothes Washer

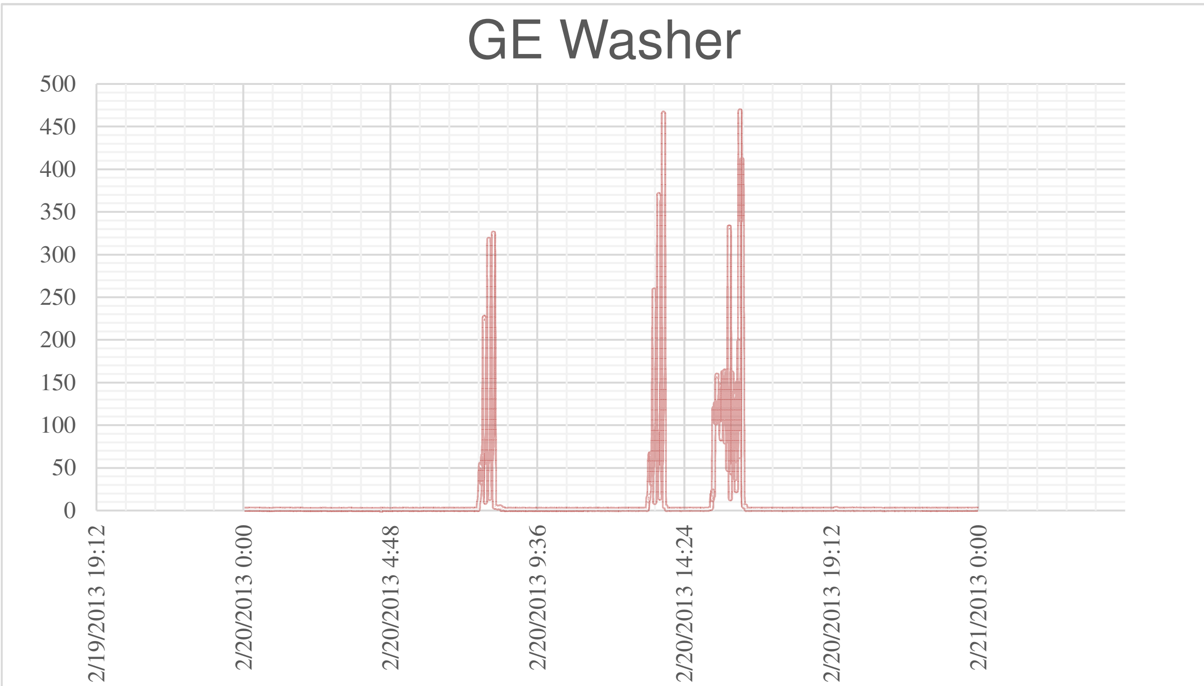


Figure E-2: Power Consumption of the GE Clothes Dryer

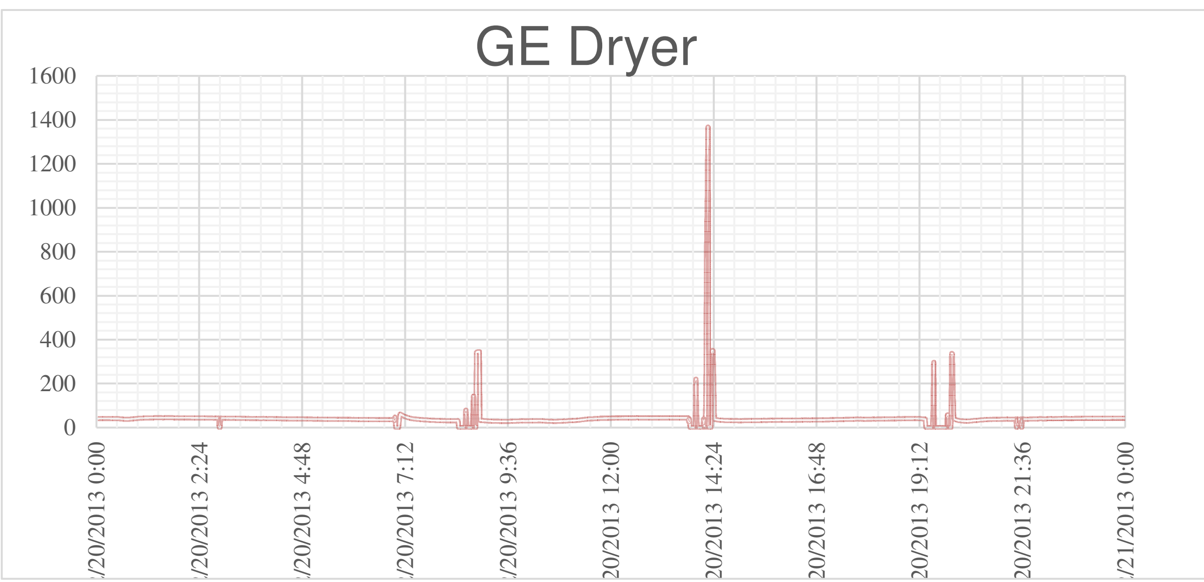


Figure E-3: Power Consumption of the GE Refrigerator

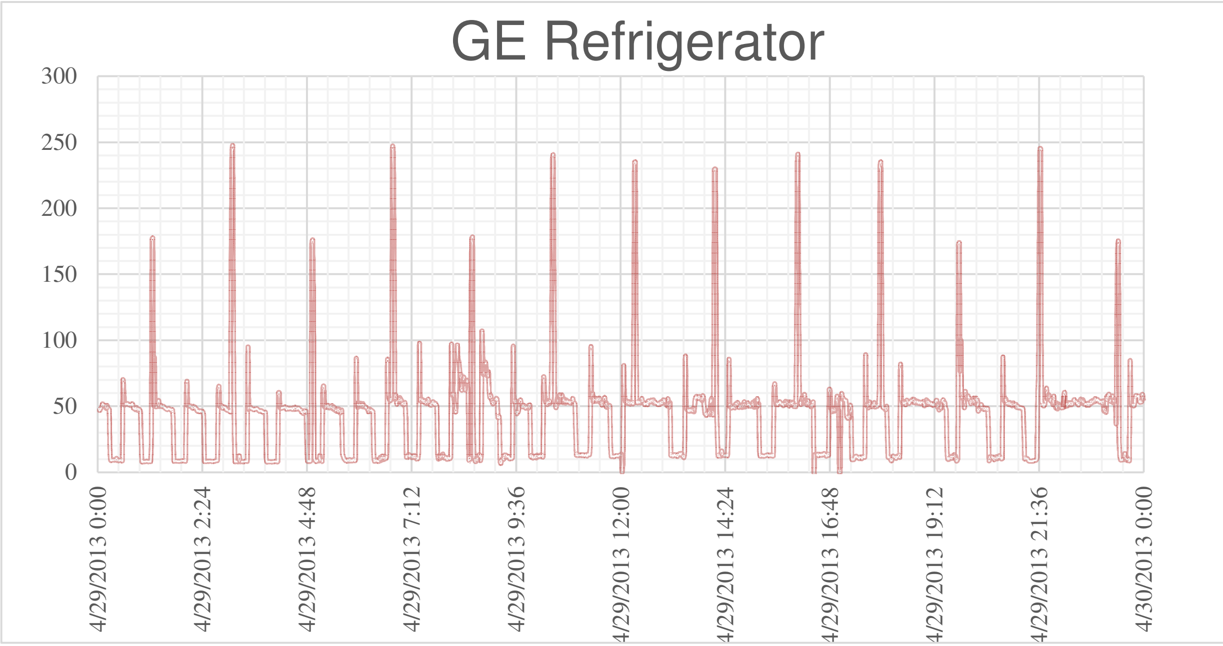
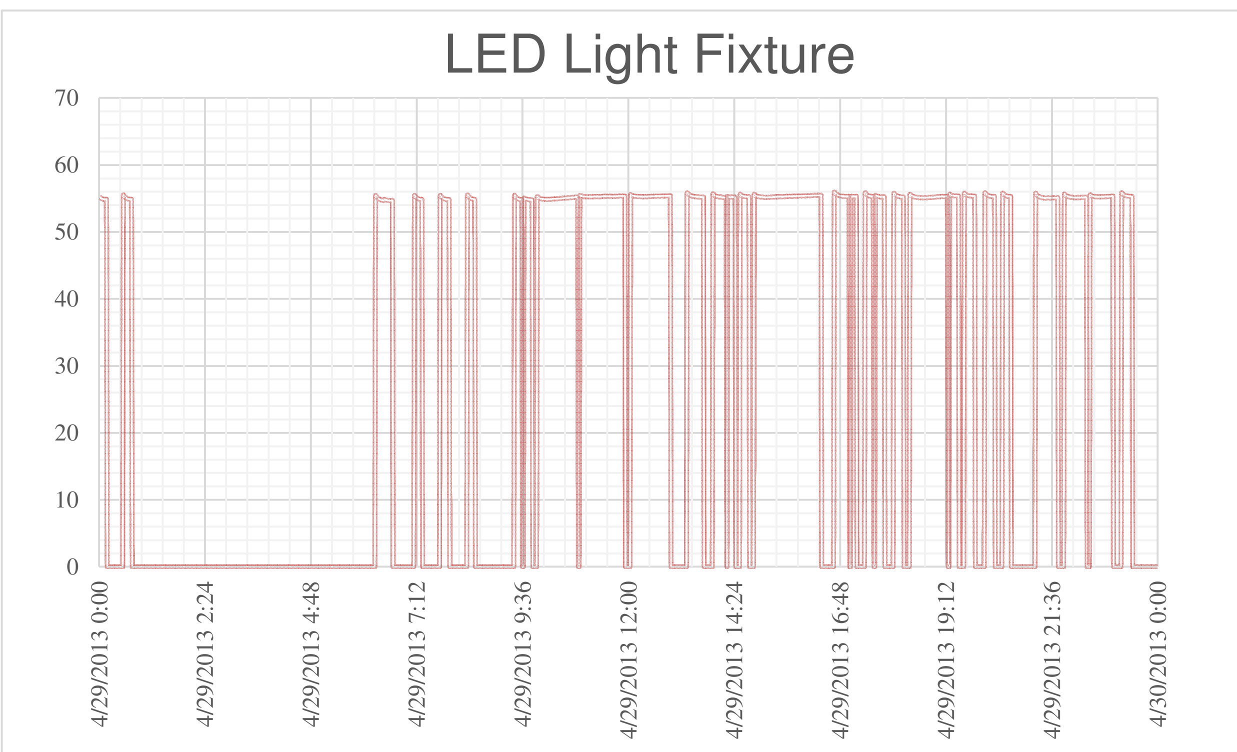


Figure E-3 shows the power draw of the GE refrigerator over a period of 24 hours. The power draw spikes (> 200 kilowatts) observed in the figure are due to the cycling of the refrigerator compressor.

Figure E-4: Power Consumption of an LED Light Fixture



In Figure E-4, the zeros indicate that the lights turned off by occupancy sensors. Using this information, the occupancy of the laundry room in the Berkeley Lab Guest House was determined to be 50 percent of the day.

Figure E-5: Aggregate Power Draw of the D2G Lab Appliances

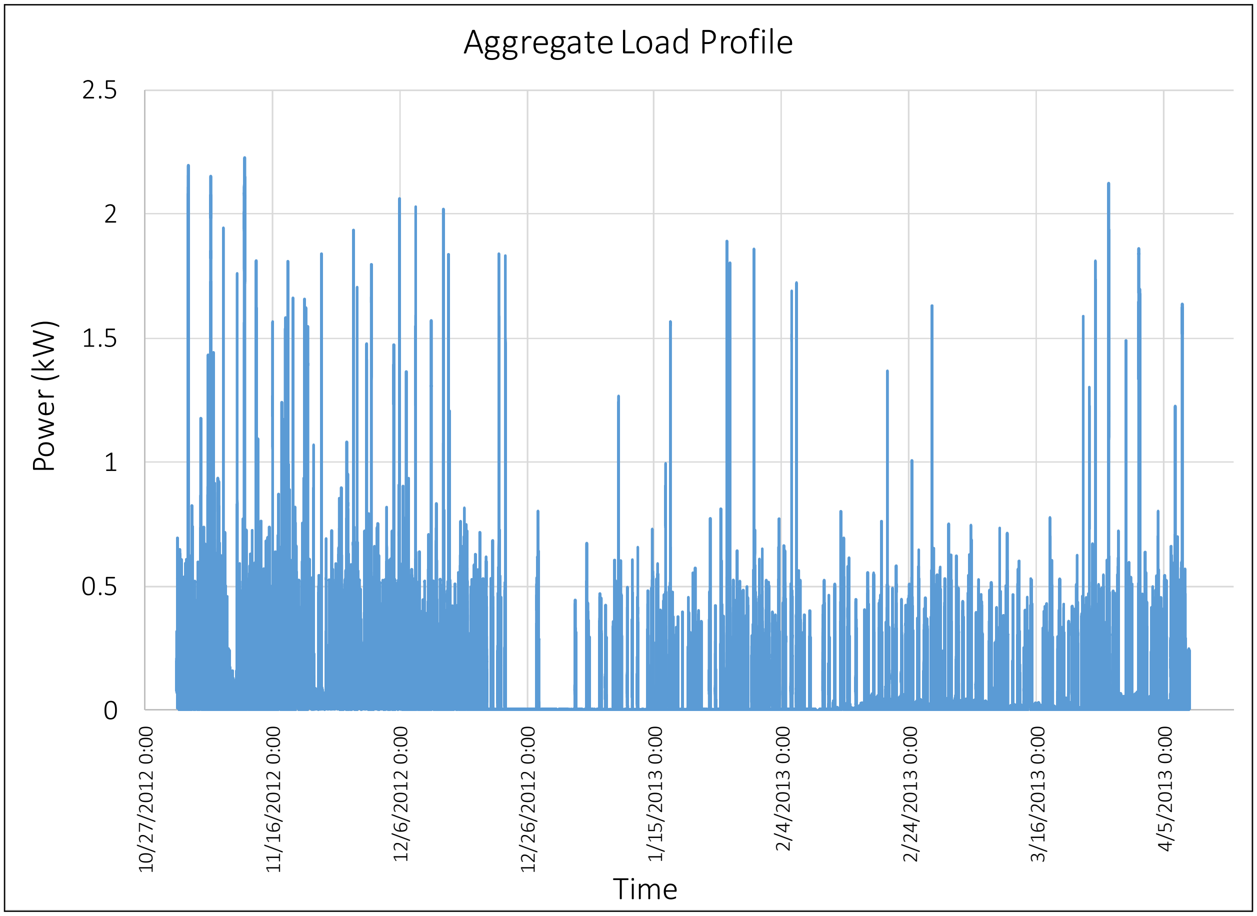


Figure E-5, shows the aggregate load profile of the washer, dryer and the refrigerator over a period of 6 months (Nov 2012 to April 2013). Since other equipment such as lights have been installed around March 2013, their power consumption data for such a long time span is not available. This chart does not include the power draw of the water heater due to the lack of power monitoring infrastructure for this appliance.